Proc. NIPR Symp. Polar Biol., 9, 325–333, 1996

STRUCTURE OF *ERIOPHORUM* TUSSOCK TUNDRA ECOSYSTEM IN NORTHERN YUKON TERRITORY, CANADA

Satoru KOJIMA

Department of Biosphere Science, Faculty of Science, Toyama University, 3190 Gofuku, Toyama 930

Abstract: Vegetation structure and soil profile characteristics of *Eriophorum* tussock tundra in northern Yukon Territory, Canada, were studied. Based on twenty sample plots, a vegetation synthesis table was constructed. Constancy and average cover values were calculated for all the vascular plant species. The following species, *Eriophorum vaginatum, Ledum decumbens, Betula glandulosa, Vaccinium vitis-idaea, Empetrum nigrum, Rubus chamaemorus, Carex lugens* and *Salix pulchra,* showed constancy class more than IV and, thus, characterized the tussock tundra vegetation. Soils were underlain permafrost at the depth of 37.4 cm on average. The thickness of the active layer varied substantially according to the kind of vegetation on it. Under *Eriophorum* tussocks it was thick (50–60 cm) whereas it was shallow (30–40 cm) under *Sphagnum* mats. Horizonation was simple and consisted of only a peat layer (Of, Om) and mineral horizon (Cz). The thickness of the peat layer was 23.0 cm on average. The total amount of organic carbon accumulated in the tussock tundra was estimated to be 13.32 kgC/m^2. Assuming that peat formation in the area started at the beginning of the Holocene and continued to the present for the past 10000 years, the annual rate of peat accretion was estimated to be 0.023 mm, far less than the rates generally reported for northern peatlands.

1. Introduction

Eriophorum tussock tundra is one of the most extensive ecosystem types in the Subarctic and Low Arctic (HANSON, 1953; CHURCHILL, 1955; WEIN and BLISS, 1974; BLISS and MATVEYEVA, 1992). It is characterized by a well developed dense, but regularly spaced, tussock formation of *Eriophorum vaginatum* L. (*sensu lato*). It is usually underlain with permafrost. It occurs on gently rolling and undulating topography. Peat accumulation is characteristic.

In recent years, *Eriophorum* tussock tundra has become a focus of attention for its role in the global carbon balance as it accumulates a considerable amount of organic matter in the form of peat, thus acting as a major carbon sink. It is, however, speculated that it may eventually turn to be a carbon source if the predicted global climatic warming (HOUGHTON *et al.,* 1990) really takes place. A conprehensive systems-model study of the tussock tundra in Alaska was conducted by MILLER *et al.* (1984).

Northern Yukon Territory, Canada, is one of the areas where well developed extensive tussock tundra is found (Fig. 1). The present study intends to analyze the structure of the *Eriophorum* tussock tundra ecosystems there and to discuss about their relevance to ecosystematic carbon balance.

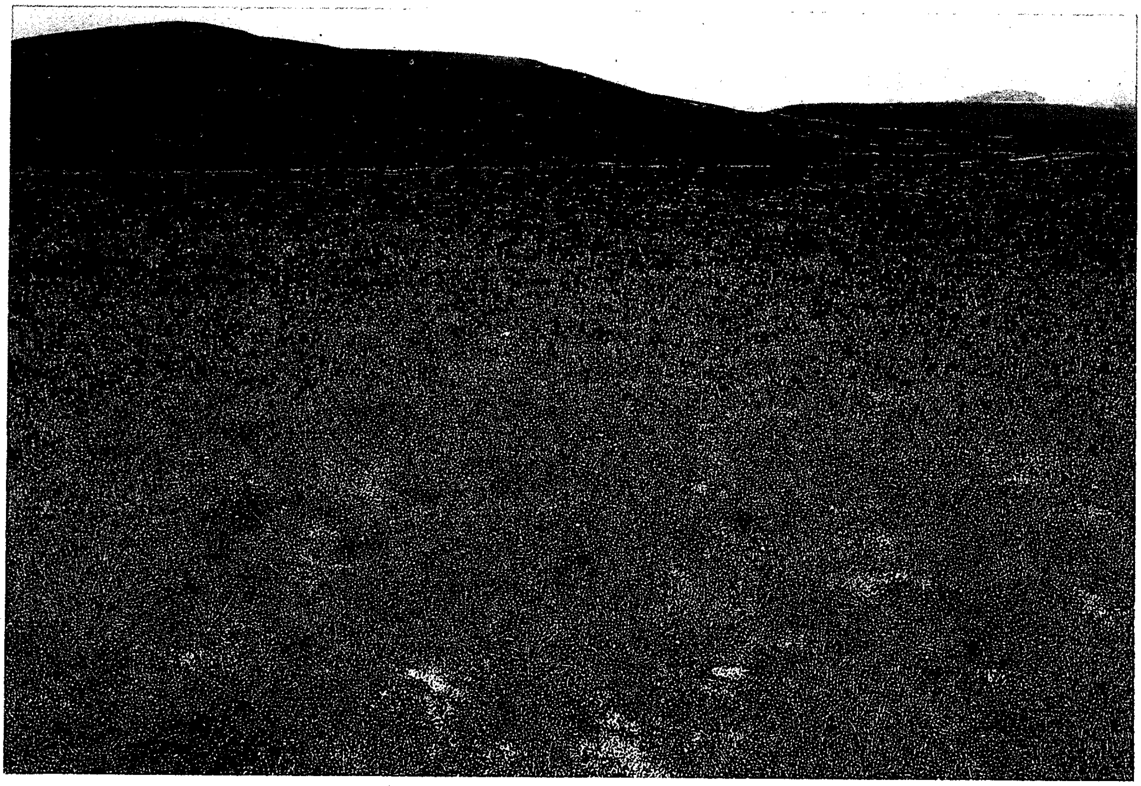

Fig. 1. A well developed Eriophorum *tussock tundra covering extensively level and gently undulating topography in northern Yukon.*

2. Study Area

The study area is located in the northern Yukon Territory, Canada (Fig. 2). It stretches along the Dempster Highway from kilometer posts 67 to 470 (64°30′ to 67°00′ N, and 136°15′ to 138°20′ W). In the area, *Eriophorum* tussock tundra is a major vegetation type covering extensive areas above the tree line, which is located approximately 1000 m above sea level in the southern part of the area and descends to approximately 700 m in the northern part of the area. It usually develops at base of slopes, in valley bottoms, and on plateaus, where drainage is imperfect, to cause permafrost formation close to ground surface.

There is no weather station which properly represents the climate of the study area. The Klondike weather station, however, can approximate the climate (Table 1). Based on the data, the climate of the area is estimated to be transitional from KÖPPEN's Dfc to ET types. CONRAD's (1946) continentality index is 47 and HOLDRIDGE's (1947) biotemperature is 2.9°C, both of which together identify the climatic division of the area Hemiarctic/OC of TUHKANEN (1984). The physiography of the area is essentially mountainous as it is located in the Ogilvie Mountains and the Richardson Mountains. But general topography is gentle almost like a peneplain. Geology is variable with layers from the Cambrian to the Cretaceous dominated by calcareous lithology (GREEN, 1972; DOUGLAS *et al.,* 1972). Unconsolidated glacier and residual deposits are extensive and are the major substrates on which the tussock tundra develops.

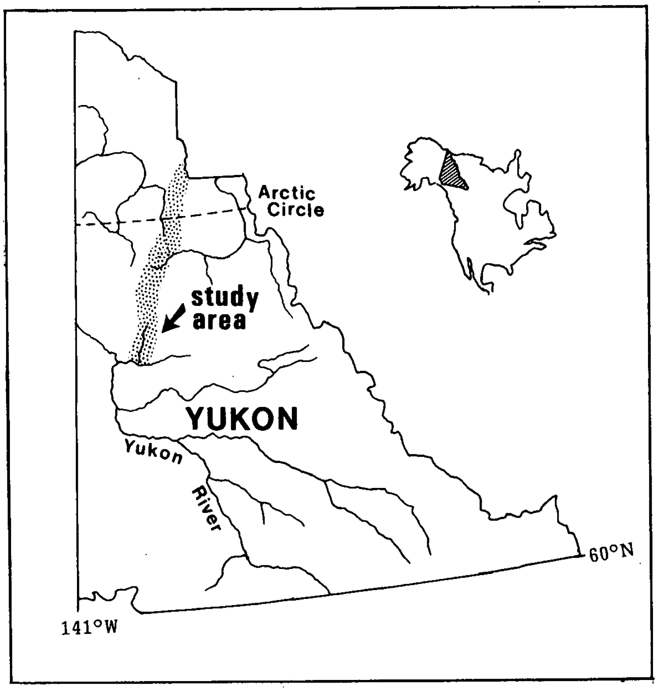

Fig. 2. Study area covers a long stretch along the Dempster Highway.

Table 1. Climatic characteristics of the study area as represented by Klondike Weather Station (64°27′N, 138°13′W, 960 m a.s.l.) (source: ATMOSPHERIC ENVIRONMENT SERVICE, 1982).

Month	Jan.	Feb.	Mar.	Apr.	May	June	July
MMT (°C)	−23.0	−17.9	−15.9	−6.7	2.7	9.3	11.5
M MAX T (°C)	−18.0	−12.2	−9.2	0.1	9.1	15.9	18.7
M MIN T (°C)	−28.5	−24.9	−22.1	−13.2	−3.1	2.6	5.1
MMTP (mm)	30	32	30	28	17	39	65
PET (mm)	0	0	0	0	42	100	113
	Aug.	Sep.	Oct.	Nov.	Dec.	Year	
MMT (°C)	8.4	2.6	−6.8	−15.8	−20.9	−6.0	
M MAX T (°C)	15.3	8.8	−1.4	−10.0	−15.6	0.1	
M MIN T (°C)	2.3	−2.9	−11.8	−20.8	−26.6	−12.0	
MMTP (mm)	69	39	41	38	40	469	
PET (mm)	83	32	0	0	0	370	

MMT: mean monthly temperature, M MAX T: mean monthly maximum temperature, M MIN T: mean monthly minmum temperature, MMTP: mean monthly total precipitation, PET: potential evapotranspiration.

3. Methods and Procedures

After extensive reconnaissance, sample plots of 5 m×5 m were established to describe vegetation, observe soil profiles, and measure soil temperature. All the vascular plants occurring in the plots were recorded and their coverage was assessed in the Domin-Krajina's species significance class (KRAJINA, 1933) as 10: 100% of coverage, 9: 99–75, 8: 74–50, 7: 49–33, 6: 32–20, 5: 19–10, 4: 9–5, 3: 4–3, 2: 2, 1: 1, and +: less than 1%. For lichens and bryophytes a composite coverage was estimated. The number of

Eriophorum tussocks was counted in a subplot of 2×2 m^2 size, which was set up at one of the corners of the vegetation plot. A soil pit was dug in each plot to the depth of a permafrost table and the horizon sequence was described. Soil temperature was measured by a thermistor thermometer (Sato Delta SK-1250) at different depths. In the laboratory, all the plots were assembled and tabulated in a vegetation synthesis table. Constancy classes were calculated according to the phytosociological procedures (BRAUN-BLANQUET, 1964). Based on the thickness of the peat layer, the total amount of organic carbon per square meter was estimated by assuming the bulk density of peat to be 0.112, and carbon content to be 51.7% of dry mass (GORHAM, 1991). Field investigations were conducted in August 1994.

4. Results and Discussions

4.1. Vegetation

A total of twenty plots were established. They were assembled and vegetation synthesis table was constructed (Table 2). The vegetation was characterized by the presence of *Eriophorum vaginatum, Ledum decumbens, Betula glandulosa, Vaccinium vitis-idaea, Empetrum nigrum, Rubus chamaemorus, Carex lugens,* and *Salix pulchra,* all of which showed a high constancy class (IV and V). Vegetative cover was high as all of the plots were completely covered by plants, without any devoid of vegetation. No tree layer developed. The shrub layer consisted of sporadic occurrences of *Betula glandulosa, Salix pulchra, Ledum decumbens,* and *Empetrum nigrum.* But they were very short in height, usually less than 30 cm tall, and did not constitute a true shrub layer. It was more natural to regard them as constituents of the herb layer as they competed with herbaceous plants for their niche space. The number of vascular species per plot ranged from 5 to 14, with an average of 9.2. The average size of the *Eriophorum* tussock was 30 cm in diameter and 10–20 cm in height. The average density of tussocks was $20.2/(2 \times 2)$ m^2. The moss layer was well developed dominated by *Sphagnum* spp. including *S. fuscum, S. nemoreum,* and *S. rubellum.* Other major mosses included *Drepanocladus revolvens, Polytrichum strictum* and *Aulacomnium palustre.* Major lichen species included *Cladonia amaurocraea, Cetraria cucullata,* and *Dactylina arctica.*

A species dominance sequence curve was drawn, following WHITTAKER (1975) (Fig. 3). It showed a negative logarithmic curve and was fitted to WHITTAKER's model C. An implication of this was that species distribution in the tussock tundra community was regulated by an indefinite number of factors; and species were, by and large, evenly sharing the niche space.

4.2. Soil profile characteristics

Horizon development was rather weak, as most profiles showed barely developed A and B horizons. In most instances, a profile was comprised of the O (peat) and C horizons. The boundary between the peat layer and mineral soil was abrupt. The average thickness of a peat layer was 23.0 cm. It was underlain with clayey mineral soil. Gleyzation was a common feature of the mineral soils.

All the plots were underlain with permafrost. The average thickness of the active layer at the time of investigation (early August 1994) was 37.4 cm, ranging from 30 to

Table 2. Vegetation structure, thickness of organic layer and depth to permafrost. Numerals for species cover are in Domin-Krajina's species significance class (Krajina, 1933).

Species Plot No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Mean	Constancy
Eriophorum vaginatum	5	6	6	7	8	8	7	8	8	8	8	8	8	7	8	8	8	8	8	8	7.5	V
Ledum decumbens	4	5	4	4	5	4	3	5	6	6	4	5	6	5	5	5	5	4	5	5	4.8	V
Betula glandulosa	6	4	4	4	4	4	4	5	4	5	5	4	5	5	4	4	5	3	2	+	4.1	V
Vaccinium vitis-idaea	+	4	1	3	4	5	3	5	6	5	4	4	5	3	3	5	4	4	3	4	3.3	V
Empetrum nigrum	.	.	.	4	5	4	4	4	4	5	4	5	5	4	4	.	.	2	4	.	2.9	IV
Rubus chamaemorus	3	4	3	.	1	.	4	.	3	3	3	.	2	4	2	+	+	+	2	3	1.9	IV
Carex lugens	+	.	.	.	+	4	.	6	4	4	.	4	3	+	+	+	.	+	.	2	1.5	IV
Salix pulchra	.	.	.	5	4	4	+	3	3	3	3	+	+	.	.	.	.	.	3	+	1.5	IV
Vaccinium uliginosum	2	.	.	4	3	4	4	3	3	.	.	.	+	.	.	.	.	.	+	+	1.2	III
Arctostaphylos rubra	.	.	.	+	3	+	.	.	1	1	1	1	+	.	.	.	.	.	.	.	0.4	III
Carex bigelowii	4	2	+	4	.	.	4	.	+	.	.	.	.	.	.	.	.	.	.	.	0.8	II
Petasites frigidus	.	.	.	4	.	1	.	.	3	2	3	.	.	.	.	.	.	.	.	.	0.7	II
Pedicularis labradorica	+	.	.	.	.	+	.	.	.	.	.	+	.	.	.	.	.	.	+	.	0.1	II
Pedicularis lanata	.	.	.	+	.	.	.	+	+	.	.	+	.	.	.	.	.	.	.	.	0.1	II
Andromeda polifolia	+	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	0.2	I
Polygonum bistorta	.	.	.	3	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.2	I
Salix phlebophylla	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.1	I
Danthonia intermedia	.	.	.	.	.	+	.	+	.	.	.	.	.	.	.	.	.	.	.	.	0.1	I
Aconitum delphinifolium	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.0	I
Calamagrostis neglecta	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.0	I
Arctostaphylos alpina	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	0.0	I
Carex podocarpa	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.0	I
Cryptogams:																						
Sphagnum spp.	7	7	6	6	6	6	8	5	7	5	6	6	4	6	8	6	7	7	8	8	6.5	V
Other mosses	3	3	2	7	6	6	6	4	4	5	5	3	4	2	3	5	5	3	2	4	4.1	V
Lichens	7	8	7	5	4	4	6	6	6	6	5	7	6	6	6	8	7	7	4	5	6.0	V
Thickness of organic layer (cm)	15	35	30	10	15	20	25	15	15	24	12	20	15	30	27	33	30	35	20	35	23.0	
Depth to permafrost (cm)	30	35	30	35	30	60	45	50	35	40	45	40	45	30	35	40	40	30	40	35	37.4	

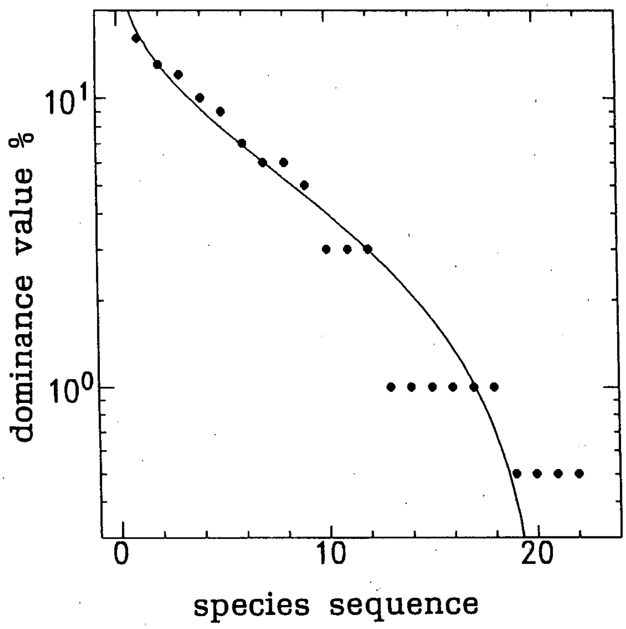

Fig. 3. A species sequence curve. The vertical axis represents relative dominance percentage of species and abscissa the sequence of species in an order of domination. For details, refer to WHITTAKER *(1975).*

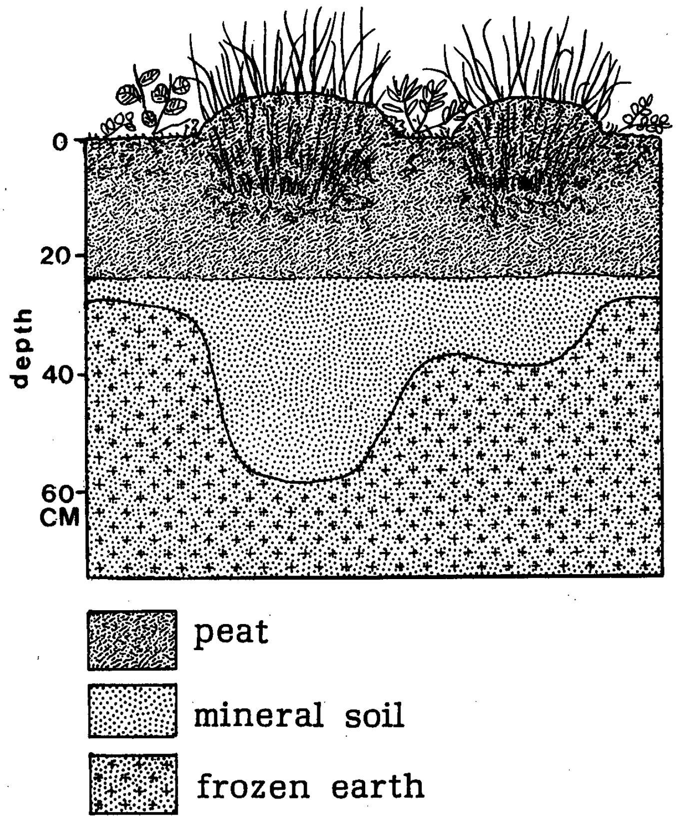

Fig. 4. An actual example of soil profile representing an Eriophorum *tussock tundra. An active layer becomes deep beneath* Eriophorum *tussock while it is shallow under* Sphagnum *mats.*

60 cm. The depth varied substantially according to vegetative cover. Under *Eriophorum* tussocks, the active layer was thick, usually more than 50 cm. It became thin under dense and compact *Sphagnum* mats as it was 30 to 40 cm (see Table 2). Thus, the permafrost table was to show an irregular bumpy surface configuration, like a mirror image of the ground surface vegetative cover (Fig. 4). This was to reflect the heat insulation effect of the vegetative cover above the permafrost. The soils were identified

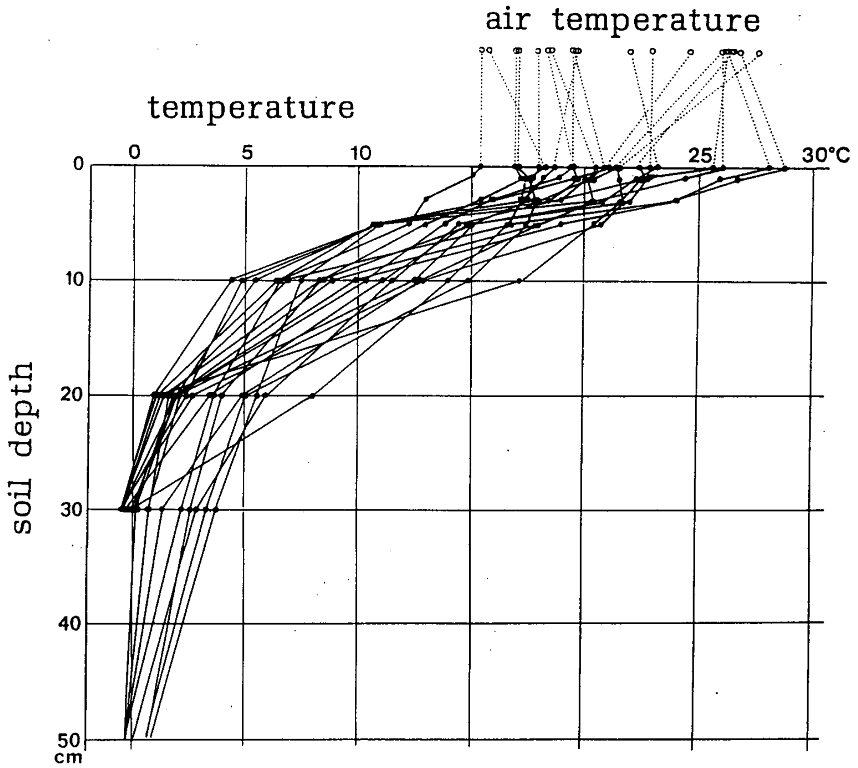

Fig. 5. Soil temperature diagram. Temperature greatly varies at the surface but it converges to the freezing point at the depth of 30–50 cm from the surface.

as Orhtic Static Cryosol or Regosolic Static Cryosol of the Canadian soil classification system (CANADIAN SOIL SURVEY COMMITTEE, 1978).

Soil temperature varied greatly at the surface, from 15.4 to 28.7°C reflecting time and weather conditions of the measurements. It converged to a freezing point at the depth of 30–50 cm (Fig. 5).

4.3. Carbon dynamics of ecosystem

In general, it is believed that peat formation in the central and northern Yukon Territory started some time in the early Holocene and has continued to the present (RITCHIE, 1987). The amount of soil organic matter in the present study was estimated to be 25.8 kg/m^2 on the average, which was equivalent to 13.3 kgC/m^2. MILLER *et al.* (1983) and OECHEL and BILLINGS (1992) reported 29 kgC/m^2 of dead organic deposits for a tussock tundra ecosystem. Assuming that peat formation in the study area started 10000 years ago and has continued to the present, the annual accumulation rate of organic carbon in the peat would be 1.33 gC/m^2. MILLER *et al.* (1983) estimated net production of the tussock tundra ecosystem to be 90 gC/m^2/year. The above-ground net primary production rate of tundra ecosystems is reported to be 48.1 g/m^2/year for northern Alaska (WEBBER, 1978) and 49.4 g/m^2/year for Devon Island, Canada (BLISS, 1977). Adding below-ground production to the above-ground, the rate will be approximately doubled. Let us assume 100 g/m^2/year to be the net production rate for the tundra ecosystems and carbon content of dry matter to be 51.7%, then 51.7 gC/m^2 is annually fixed and deposited in the ecosystems. This implies that, in the study area, 2.6% of the fixed carbon has been and is being deposited in the form of peat. The annual accretion rate of peat layer in this study is calculated to be 0.023 mm. This is a much smaller rate than those generally reported for northern peatlands, *i.e.*, 0.2–0.8 mm/year (GORHAM, 1991).

There are two possible interpretations for this, *i.e.*, 1) carbon fixation has been well balanced with decomposition rate, thus, only a small fraction of the carbon was deposited in the peat; and 2) the decomposition rate of peat became substantially increased some time ago exceeding the rate of peat accumulation, resulting in fast consumption and reduction of peat which had been once accumulated. OECHEL and BILLINGS (1991) pointed out a problem with *Eriophorum* tussock tundra. They raised the question of whether in recent years the tussock tundra in northwestern North America was in fact losing carbon much faster than once believed. Direct measurements indicated that the tussock tundra ecosystem in Toolik Lake, Alaska, was actually losing carbon at the rate of 180–360 g/m^2/year. This tendency was consistent with recent measurements along a latitudinal transect in northern Alaska from Toolik Lake to Prudhoe Bay. They regarded this as a result of recent climatic warming for the last century, especially for the past few decades. Temperature has indeed increased 2–4°C in the last century on Alaska's North Slope and adjacent northwestern Canada (OECHEL and BILLINGS, 1991). According to CHAPMAN and WALSH (1993), surface air temperature in northwestern North America exhibited the highest rate of increase, more than 0.75°C per decade, for the period 1961–1990. OECHEL and BILLINGS (1991) stated that, if the above-mentioned hypothesis were correct, organic carbon deposited as peat in the region would be completely lost in 15 years. KOIZUMI *et al.* (1995) recognized that soil respiration rate from peat soil is positively correlated with soil temperature and negatively with soil water content. This implies that peat soils can be rapidly decomposed if temperature increases and soil becomes dried. It is not clear if this is the case for the present study. This problem needs further thorough study.

References

ATMOSPHERIC ENVIRONMENT SERVICE (1982): Canadian Climate Normals 1951–1980, Temperature and Precipitation, the North—Y.T. and N.W.T. Ottawa, Environment Canada, 55 p.

BLISS, L.C. (1977): General summary, Truelove Lowland ecosystem. Truelove Lowland, Deveon Island, Canada: A High Arctic Ecosystem, ed. by L.C. BLISS. Edmonton, Univ. Alberta Press, 657–675.

BLISS, L.C. and MATVEYEVA, N.V. (1992): Circumpolar arctic vegetation. Arctic Ecosystems in a Changing Climate; An Ecophysiological Perspective, ed. by F.S. CHAPIN III *et al.* San Diego, Academic Press, 59–89.

BRAUN-BLANQUET, J. (1964): Pflanzensoziologie, 2nd ed. Wien, Springer, 865 p.

CANADIAN SOIL SURVEY COMMITTEE (1978): The Canadian system of soil classification. Res. Br., Can. Dept. Agr., Publ. **1646**, 164 p.

CHAPMAN, W.L. and WALSH, J.E. (1993): Recent variations of sea ice and air temperature in high latitudes. Bull. Am. Meteorol. Soc., **74**, 33–47.

CHRUCHILL, E.D. (1955): Phytosociological and environmental characteristics of some plant communities in the Umiat Region of Alaska. Ecology, **36**, 606–927.

CONRAD, V. (1946): Usual formulas of continentality and their limits of validity. Trans. Am. Geophys. Union, **27**, 663–664.

DOUGLAS, R.J.W., GABRIELSE, H., WHEELER, J.O., STOTT, D.F. and BELYEA. (1972): Geology of western Canada. Geology and Economic Minerals of Canada, ed. by R.J.W. DOUGLAS. Ottawa, Dept. Energy, Mines and Resources, Canada, 366–488.

GORHAM, E. (1991): Northern peatlands: Role in the carbon cycle and probable responses to climatic warming. Ecol. Appl., **1(2)**, 182–195.

GREEN, L.H. (1972): Geology of Nash Creek, Larsen Creek, and Dawson-map areas, Yukon Territory. Ottawa, Dept. Energy, Mines and Resources, Canada, 157 p. + 3 maps.

HANSON, H.C. (1953): Vegetation types in northwestern Alaska and comparisons with communities in other arctic regions. Ecology, **34**,111–140.

HOLDRIDGE, L.R. (1947): Determination of world plant formations from simple climatic data. Science, **105**, 367–368.

HOUGHTON, J.T., JENKINS, G.J. and EPHRAUMS, J.J. (1990): Climate Change: The IPCC Scientific Assessment. Cambridge, Cambridge Univ. Press, 365p.

KOIZUMI, H., NAKADAI, T., BEKKU, Y., KONTTURI, M. and MELA, T. (1995): CO_2 efflux from soil in three soil-type agro-ecosystems in Finland. Proceedings of the International Arctic Science Symposium. Science and technology Agency, Japan Marine Science and Technology Center. D-89–96.

KRAJINA, V.J. (1933): Die Pflanzengesellschaften des Mlynica-Tales in den Visoke Tatry (Hohe Tatra). Bot. Centralb. Beih. Abt. II, Bd. L. Heft., **3**, 774–957.

MILLER, P.C., KENDALL, R. and OECHEL, W.C. (1983): Simulating carbon accumulation in northern ecosystems. Simulation, **40**, 119–131.

MILLER, P.C., MILLER, P.M., BLAKE-JACOBS, M., CHAPIN, III, F.S., EVERETT, K.R., HILBERT, D.W., KUMMEROW, J., LINKINS, A.E., MARION, G.M., OECHEL, W.C., ROBERTS, S.W. and STUART, L. (1984): Plant-soil processes in *Eriophorum vaginatum* tussock tundra in Alaska: A systems modeling approach. Ecol. Monogr., **54**, 361–405.

OECHEL, W.C. and BILLINGS, W.D. (1992): Effects of global change on the carbon balance of arctic plants and ecosystems. Arctic Ecosystems in a Changing Climate; An Ecophysiological Perspective, ed. by F.S. CHAPIN III *et al.* San Diego, Academic Press, 139–168.

RITCHIE, R.C. (1987): Postglacial Vegetation of Canada. Cambridge, Cambridge Univ. Press, 178 p.

TUHKANEN, S. (1984): A circumboreal system of climate-phytogeographical regions. Acta Bot. Fenn., **127**, 1–50.

WEBBER, P.T. (1978): Spatial and temporal variation of the vegetation and its production, Barrow, Alaska. Ecol. Stud., **29**, 37–112.

WEIN, R.W. and BLISS, L.C. (1974): Primary production in arctic cottongrass tussock tundra communities. Arct. Alp. Res., **6**, 261–274.

WHITTAKER. R.H. (1975): Communities and Ecosystems. 2nd ed. New York, MacMillan, 385 p.

(Received January 24, 1995; Revised manuscript accepted July 27, 1995)